A Real Time Tracking Method for Unmanned Traffic Vehicle Paths Based on Electronic Tags

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Abstract. In order to improve the real-time tracking accuracy of the path and reduce tracking bias, a real-time path tracking method for unmanned vehicles based on electronic tags is proposed. Firstly, electronic tags are used to collect the path information of non human traffic vehicles. Secondly, based on the collected information, an improved Pure Pursuit algorithm is used to calculate the curvature of the pedestrian free flow vehicle path. Finally, construct an objective function for real-time path tracking, and solve the objective function to achieve real-time tracking of unmanned vehicle paths. The experimental results show that compared with existing tracking methods, the real-time tracking accuracy of the proposed method is consistent with the actual path, and the tracking deviation is significantly reduced.

Keywords: Electronic Labels · No Character Streaming Car · Real Time Path Tracking

1 Introduction

The unmanned factory is an important embodiment of the fact of intelligent factory. The unmanned factory logistics is the key technology to realize the unmanned factory, and the vehicle path tracking technology is one of the core technologies of the unmanned logistics vehicle driving system [1]. Vehicle autonomous driving is a hot research field at present, aiming at the special scenes of enclosed factories and the point-to-point vehicle autonomous driving that can be completely unmanned, such as the unmanned logistics system of factory materials transportation [2, 3]. The realization of unmanned logistics in the factory area can improve the automation and intelligence of the factory area, ensure the working environment of employees, improve logistics efficiency and reduce the cost of logistics in the factory area. The unmanned logistics vehicle mainly adopts the vehicle with specific driving device as the traction vehicle, and uses the support hook device to mount multiple material trailers behind the tractor. In order to achieve the purpose of flexible steering. Compared with ordinary passenger cars, unmanned logistics tractor is more sensitive to the change of front wheel deflection Angle due to the short wheelbase of front and rear wheels, and has higher requirements on the accuracy of vehicle lateral

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control and control model. Path tracking control is one of the core technologies for the implementation of unmanned logistics vehicles, that is, by obtaining the real-time trajectory planned by the vehicle in real time, the effective path tracking algorithm is used to realize the control of the vehicle, so as to achieve the purpose of the vehicle driving on the correct route.

Reference [4] proposes a real-time path tracking method for unmanned vehicles based on the improved Stanley algorithm. Based on the characteristics of the vehicle's heading angle, lateral deviation, vehicle speed, and appropriate preview distance, a pure tracking algorithm is used to improve the calculation method of wheel angle in the Stanley algorithm. A new fusion algorithm is proposed to calculate the appropriate wheel angle of the vehicle at the current speed in real-time. Reference [5] proposed a real-time path tracking method for vehicles without people based on fuzzy Sliding mode control. First, the vehicle model was established based on the dynamic characteristics of two degrees of freedom; Secondly, in order to reduce the chattering problem caused by conventional Sliding mode control, a fuzzy sliding mode controller with adaptive switching gain adjustment function is designed. Finally, a joint simulation platform for unmanned vehicle path tracking was built based on Simulink/Carsim software.

In order to improve the tracking reliability of unmanned vehicles, a real-time tracking method for unmanned vehicle paths based on electronic tags is proposed.

2 Path Information Collection of Unmanned Logistics Vehicles Based on Electronic Tags

Warehouse identification number of a supply chain member. A supply chain member can have multiple warehouses, and the warehouse identification number is used to uniquely identify a warehouse [6–8]. Warehouse is the place where products are stored, and also the place where readers identify product information. Usually, a reader is placed at the entrance and exit of the warehouse respectively to capture the warehousing and discharging time of products, as shown in Fig. 1.

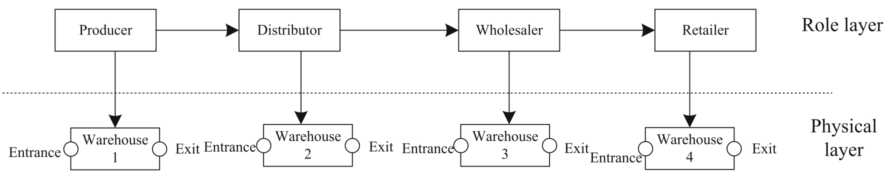


Fig. 1. Path node of unmanned logistics vehicle

The basic principle of product logistics path tracking based on electronic labels is to set up readers and writers at the entrances and exits of warehouses of supply chain members. When the product manufacturer produces the product, they attach a unique product electronic code to the product and write it into the attached electronic label. When the product with the electronic label passes through the entrances and exits of these warehouses, the reader and writer will automatically capture the product identification code, And record the system time when the product was identified, thus forming an information node that records the product logistics path. A series of information nodes arranged in chronological order form the entire logistics path that the product has passed through. Decision makers can use this path information to query and track the historical status of the product, and also know the current location and status of the product [9–11]. The structure of a typical product logistics path tracking system based on electronic tags is shown in Fig. 2.

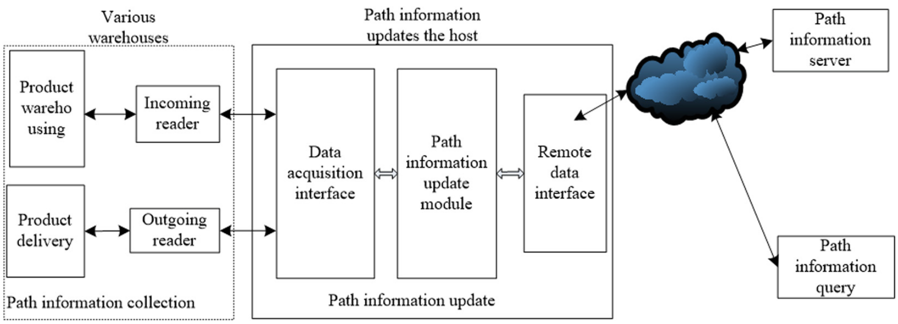


Fig. 2. Principle of path tracking data acquisition based on electronic tag

It consists of four functional modules: path information collection system, path information update system, path information storage system and path information query system. Its functions are as follows:

(1) Path information collection system. The core of the path information collection system is product coding and product identification. In logistics path tracking systems based on electronic tags, EPC codes are usually used as the unique identification codes for products. The EPC code Auto-ID research center proposes a coding standard for electronic labels, which enables all goods worldwide to have a unique identifier, and its biggest feature is the ability to identify individual products. The product identification system includes electronic labels and readers. Each product is accompanied by an electronic label, which contains the EPC code as the unique code of the product. When electronic tags with EPC codes are stored in the sensing area of the reader, the EPC code will be automatically captured by the reader, achieving automated product identification. The system time when the product is identified is combined with the reader number, reader position, warehouse number, and supply chain member angle to form a logistics path information node. According to different purposes, readers can be divided into inbound readers and outbound readers, and the corresponding logistics path information nodes generated are entry information nodes and exit information nodes, respectively [12–14]. The functions of inbound and outbound readers are as follows:

① Incoming reader: it is set at the entrance of the warehouse to automatically identify the products entering the warehouse, automatically record the incoming time of the products, provide information collection support for generating the entry information node, and transmit to the path information update module through the data collection interface for corresponding processing;

(2) Outgoing reader: set at the warehouse exit, automatically identifies the products leaving the warehouse, automatically records the time of the products leaving the warehouse, provides information collection support for generating the export information node, and transmits to the path information update module through the data collection interface for corresponding processing [15].
(3) Path information update system. The path information update system is a management software residing in the path information update host. It is composed of data acquisition interface, path information update module and remote data interface. They perform the following functions:
(4) Data acquisition interface: it is the communication bridge between the path information acquisition system and the path information update system. It transmits the product EPC code and product identification time stamp captured by the path information acquisition system to the path information update module for corresponding processing;

② Path information update module: The path information update module is the core of the path information update system. It receives product identification timestamp information from the path information collection system through a data collection interface, generates entry information nodes or exit information nodes based on the purpose of the reader and writer, and then updates the path information record of the path information storage system through a remote data interface to expand new information nodes. When the product is recognized by different readers and writers, new path information nodes continue to expand and path information records constantly refresh. The process of updating path information is shown in Fig. 3.

③ Remote data interface: It is the bridge of communication between the path information update system and the path information storage system. Because the path information is stored in an independent product path information server in a standard XML format, the path information update system and the path information storage system exchange information through the client/server mode. The path information server usually provides standard remote access interfaces, such as SOAP interface, which allows message exchange between different applications through HTTP communication protocol and in XML format. Therefore, the path information update system of various platforms can update path information through standard remote data interface, which has good platform independence.

(3) Path information storage system. The path information is stored in a standard XML format on an independent path information server (usually also known as a PML server), which is generally established and maintained by the product manufacturer and authorized to downstream supply chain members for path updates. Usually, a good path information storage system should have two conditions: ① standardization of path information storage format; ② Standardization of path information access interfaces. This is achieved through XML and SOAP interfaces, which complement each other and together provide a standard set of information access patterns for clients.

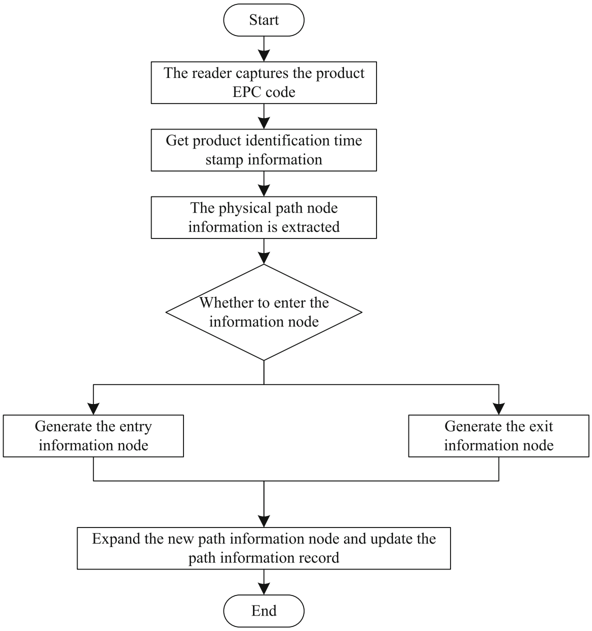


Fig. 3. Path information update process

(4) Path information query system. The path information query system is a functional part that directly provides product path information support and decision-making basis for supply chain members or decision-makers. For a product logistics path tracking system, its supported query functions are as follows:

① Full path query: query the information of all path nodes that the product passes through from production to the current state;

(2) Path query in a certain time period: query the information of the path nodes passed by the product in a specified time interval;
(3) The upstream member query of the supply chain: the information of the upstream member node of a certain member node in the supply chain is logically realized by determining all the leading nodes of the node.
(4) The downstream member query of the supply chain: the query of the downstream member node information of a certain member node in the supply chain is realized logically by determining all subsequent nodes of the node;

⑤ Product direct source query: the query of the product direct source node of a member node in the supply chain is realized logically by determining the close preceding node of the node;
⑥ Direct flow of products query: The query of the direct flow of products of a member node in the supply chain is logically realized by determining the close node of the node.

3 Calculation of Path Bending Degree of Unmanned Logistics Vehicle

After collecting the path information of the unmanned flow vehicle, the improved Pure Pursuit algorithm is used to calculate the curvature of the unmanned flow vehicle path.

At present, kinematics bicycle models or dynamic bicycle models are mostly used in real-time path tracking. One kinematics bicycle model is not listed. Assuming that the wheel speed is always the same as the actual running speed of the vehicle, Fig. 4 shows the Pure Pursuit algorithm based on the two wheel bicycle model.

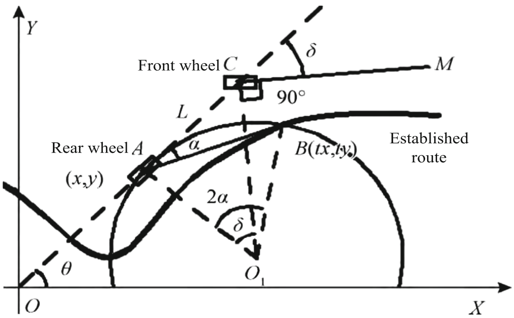


Fig. 4. Pure Pursuit algorithm based on the two-wheeled bicycle model

As shown in Fig. 4, the vehicle is assumed to be A two-wheel bicycle model, and the front and rear wheels are represented by C and A respectively. The model approximately describes its motion at low speed and medium Angle, and can be used to update its motion state. Among them, the update equation of position (x, y) and heading Angle (θ) of the unmanned logistics vehicle is:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} v\cos\theta \\ v\sin\theta \\ \frac{v\tan\delta}{L} \end{bmatrix} \tag{1}$$

In the formula, L represents the wheelbase between the front and rear wheels AC of the unmanned flow vehicle, determined based on actual measurement values. v represents the current speed of the unmanned flow vehicle, and δ represents the angle of rotation in the current heading direction of the unmanned flow vehicle. Counterclockwise is positive, and clockwise is negative.

In triangle AOC, using the trigonometric function relationship, it can be known that the rotation angle is:

$$\delta = \arctan\frac{L}{R} \tag{2}$$

In the formula, R represents the radius of the unmanned logistics vehicle when turning.

In the Pure Pursuit algorithm, the rear-wheel steering motion of unmanned logistics vehicles is approximated as a part of a circle. In triangle AOC, sine theorem is used to show that:

$$\frac{L_f}{\sin(2\alpha)} = \frac{R}{\sin(2\pi - \alpha)} \tag{3}$$

In the formula, L_f represents the forward looking distance between the current position A of the unmanned vehicle and the target point B, while α represents the angle at which the unmanned vehicle turns from the current heading direction (AC) towards the target point direction (AB), which is the heading angle deviation. Counterclockwise is positive, and clockwise is negative.

From the above formula, it can be seen that the turning angle of a pedestrian free vehicle is:

$$\delta = \tan^{-1}\left(\frac{2L\sin\alpha}{L_f}\right) \tag{4}$$

For local areas, the specific value of α needs to be analyzed according to the direction between the current position of the unmanned logistics vehicle and the target point of the predetermined path, and the specific relationship is shown in Fig. 5.

As shown in Fig. 5, if the unmanned vehicle position at a certain moment is (x, y) and the target point coordinate is (tx, ty), then β can be represented as:

$$\beta = \tan^{-1}\frac{ty - y}{tx - x} \tag{5}$$

In the formula, β represents the Angle between the line between the current position A and the target point B and the positive direction of axis x.

According to Fig. 5 (a) and 5 (b), when the target point is located on the left side of the trajectory, the relationship between α, β and θ is:

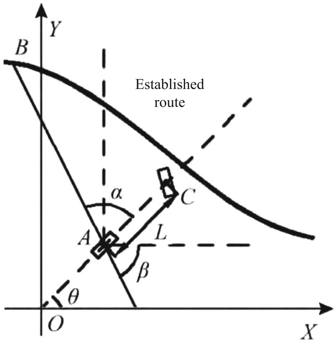
$$\begin{cases} \alpha = \beta - \theta - \pi, \theta \in (-\pi, \beta] \\ \alpha = \beta - \theta + \pi, \theta \in [\beta, \pi] \end{cases} \tag{6}$$

As shown in Fig. 5 (c), when the target point is located at the upper right of the trajectory, the relationship between α, β, and θ is:

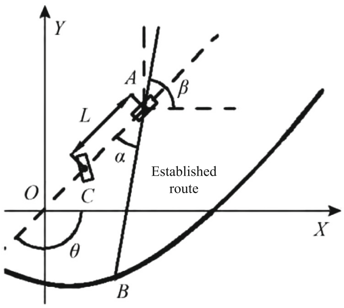
$$\begin{cases} \alpha = \beta - \theta, \theta \in (\beta - \pi, \pi] \\ \alpha = \beta - \theta - 2\pi, \theta \in [-\pi, \beta - \pi] \end{cases} \tag{7}$$

According to Fig. 5 (d), when the target point is located at the lower right of the trajectory, the relationship between α, β and θ is:

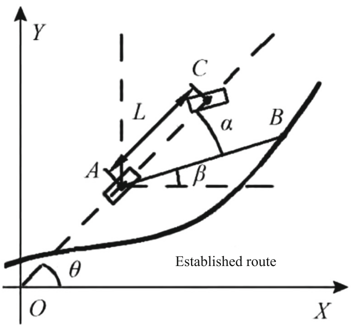
$$\begin{cases} \alpha = \beta - \theta, \theta \in (-\pi, \pi + \beta] \\ \alpha = \beta - \theta + 2\pi, \theta \in [\pi + \beta, \pi] \end{cases} \tag{8}$$



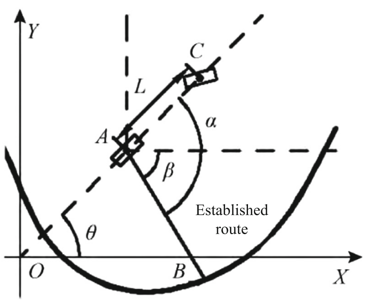
(a) The target point is located at the top left of the trajectory



(b) The target point is located at the bottom left of the trajectory



(c) The target point is located at the top right of the trajectory



(d) The target point is located at the bottom right of the trajectory

Fig. 5. Interrelationship between target points and trajectories

Through the above calculation, the heading angle deviation α of the unmanned flow vehicle can be obtained. According to formula (4), the steering wheel angle δ can be calculated, and the steering wheel angle command can be transmitted to the executing mechanism to control the angle corresponding to the steering wheel angle.

In order to ensure the smoothness and continuity of speed changes of unmanned flow vehicles on paths with significant curvature changes, an improved algorithm for forward looking distance is proposed based on existing theories, which can be expressed as:

$$\begin{cases} L_f = \frac{1}{2a_{\max}}v^2 + k_3 v + L_{fc} \\ v = \frac{v_{\max} - v_{\min}}{(C_2 - C_1)^2}(C_2 - C_1)^2 + v_{\min} \end{cases} \tag{9}$$

In the formula, $a_{\max}$ is the maximum braking acceleration, k_3 is the speed coefficient, L_{fc} is the initial looking distance, where the minimum turning radius of the unmanned logistics vehicle is taken, C_1 is the maximum bending degree of a given path, C_2 is the minimum bending degree of a given path, $v_{\min}$ is the minimum speed of the unmanned logistics vehicle set in advance, and $v_{\max}$ is the maximum speed of the unmanned logistics vehicle set in advance.

Formula (9) can reduce the speed and forward looking distance as the road curvature increases, and achieve continuous changes in speed without the need to set the speed into high, medium, and low gears based on experience for the curvature range. The improved algorithm can achieve adaptive changes in speed with the curvature of a given path, based on the maximum and minimum values of the driving speed of a pedestrian free vehicle.

The method for determining the target point is shown in Fig. 6.

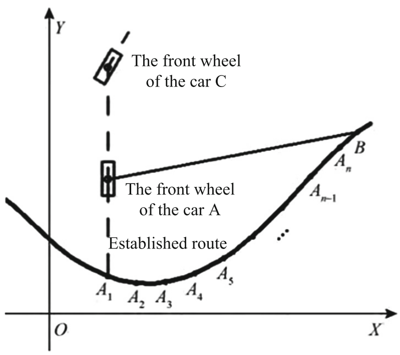


Fig. 6. Target point determination method

Given A predetermined path, firstly, the nearest point from the predetermined path is selected as A_1 based on the current position of the unmanned logistics vehicle. Then, the adjacent points behind point A_1, which is consistent with the forward direction of the unmanned logistics vehicle, are added successively. When the desired sum is greater than the corresponding forward distance L_f at the current speed, the point is selected as the target point B.

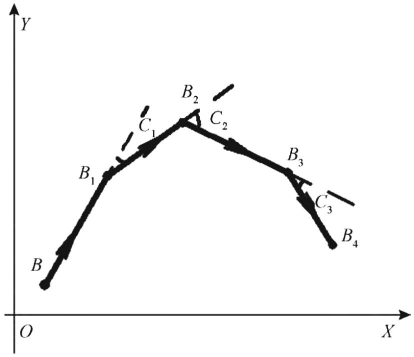


Fig. 7. Determination method of bending degree

The determination method of bending degree is shown in Fig. 7.
The solution formula for curvature C can be expressed as:

$$C = \sum_{i=1}^{3} c_i \tag{10}$$

In the formula, c_i is the Angle between two adjacent broken lines.

4 Real Time Tracking of Traffic Paths Without People

Nonlinear model predictive controller can solve the nonlinear problems of the system, but the solution speed is slow when using fmincon solver, especially when the prediction time domain and control time domain are long, nonlinear model predictive control will lose large real-time performance. Therefore, for the nonlinear vehicle model, the linearization optimization can be converted into the quadratic programming problem with faster solving speed.

In this section, the magic formula of the tire is used in the analysis of the dynamics of the unmanned vehicle tire. Assuming that the camber Angle is 0 and the tire is unchanged, the magic formula can be linearized at the working point $(\alpha_0, F_0(\alpha))$:

$$F_c(\alpha) = K\alpha + \lambda \tag{11}$$

In the formula, $K = \frac{dF_c}{d\alpha}$ and $\lambda = F_0 + K \cdot S_h - K(\alpha + S_h)$.

Considering the constant speed of unmanned vehicles and considering the assumption of small front wheel angles, a 2 degree of freedom model for lateral and yaw is established using Newton's second law:

$$\begin{cases} m(\ddot{y} + v_x\dot{\varphi}) = 2F_{ef} + 2F_{cr} \\ I_z\ddot{\varphi} = 2aF_{cr} - 2bF_{cr} \end{cases} \tag{12}$$

In the formula, a and b are the distance from the center of mass of the unmanned logistics vehicle to the front and rear axle, m is the mass of the vehicle, I_z is the moment of inertia of the unmanned logistics vehicle around axis z, F_{ef} and F_{cr} are the lateral force of the front and rear wheels, y is the lateral displacement of the center of mass of the unmanned logistics vehicle, v_x is the longitudinal velocity of the center of mass of the unmanned logistics vehicle, and φ is the yaw Angle.

By substituting formula (11) into formula (12), we can get:

$$\begin{cases} \ddot{y} = -v_x\dot{\varphi} + \frac{2}{m}\left[K_{cf}\left(\delta_f - \frac{\delta_f}{v_x}\right) - K_{cr}\frac{\dot{y}-b\dot{\varphi}}{v_x}\right] + \frac{2\lambda_{cf}+2\lambda_{cr}}{m} \\ \ddot{\varphi} = \frac{2a}{I_z}\left[K_{cf}\left(\delta_f - \frac{\dot{y}+a\dot{\varphi}}{v_x}\right)\right] + \frac{2b}{I_z}K_{cr}\frac{\dot{y}-b\dot{\varphi}}{v_x} + \frac{2(\lambda_{cf}a-\lambda_{cr}b)}{v_x} \end{cases} \tag{13}$$

In the formula, K_{cf}, K_{cr}, λ_{cf}, and λ_{cr} represent the parameters K and λ after linearizing the front and rear wheel lateral forces.

The Taylor series is used to expand at the working point G, ignoring the higher-order term, and the following results are obtained:

$$\dot{Y} = \dot{y}\cos\varphi_r + v_x\sin\varphi_r + v_x\varphi\cos\varphi_r - \dot{y}_r\varphi\sin\varphi_r \tag{14}$$

Thus, the whole unmanned logistics vehicle system can be written as an incremental linear time-varying state space expression:

$$\begin{cases} \dot{x}(t) = A(t) + B(t)u(t) + D(t) \\ y(t) = Cx(t) \end{cases} \tag{15}$$

For this continuous state space equation, the first order difference quotient method is used for discretization to obtain the discrete state space expression:

$$\begin{cases} x(k+1) = A(k)x(k) + B(k)u(k) + D(k) \\ y(k+1) = Cx(k+1) \end{cases} \tag{16}$$

In the formula, $A(k) = I + TA(t)$, $B(k) = TB(t)$, $D(k) = TD(t)$ and T represent sampling time.

Suppose:

$$\xi(k) = \begin{bmatrix} x(k) \\ u(k-1) \end{bmatrix} \tag{17}$$

Change formula (16) to incremental model:

$$\begin{cases} \dot{\xi}(k+1) = \tilde{A}(k)\xi(k)\Delta u(k) + \tilde{D} \\ \eta(k+1) = \tilde{C}(k)\xi(k) \end{cases} \tag{18}$$

According to the basic idea of model predictive control, by setting control time domain N_c and prediction time domain N_p, and $N_c \leq N_p$, the output in the prediction time domain can be written as:

$$Y(k+1) = \begin{bmatrix} \eta(k+1) \\ \eta(k+2) \\ \vdots \\ \eta(k+N_p) \end{bmatrix} \tag{19}$$

Write the input quantity in time domain N_c as a vector:

$$\Delta U(k) = \begin{bmatrix} \Delta u(k) \\ \Delta u(k+1) \\ \vdots \\ \Delta u(k+N_c-1) \end{bmatrix} \tag{20}$$

According to the model predictive control principle, the system output equation at time k can be obtained:

$$Y(k+1) = S_t \xi(k) + S_u \Delta U(k) + \Phi \tilde{D} \tag{21}$$

Due to the complexity of the unmanned vehicle dynamics model itself, a relaxation factor was added to the design of the objective function, which is:

$$J(\xi(t), u(t-1), \Delta U(t)) = \sum_{i=1}^{N_p} \|\Delta\eta(t+i)\|_Q^2 + \sum_{i=1}^{N_c-1} \|\Delta u(t+i)\|_R^2 + \rho\varepsilon^2 \tag{22}$$

In the formula, $\Delta\eta(t+i)$ is the deviation between the predicted output and the reference trajectory in the forecast time domain; ε is the relaxation factor; ρ is the weight coefficient of the relaxation factor; Q is the weight coefficient of the output deviation; R is the weight coefficient of the control increment.

Suppose:

$$E(t) = S_\xi \xi(k) + \Phi \tilde{D} - Y_{ref} \tag{23}$$

By substituting formula (22), it can be converted into a standard Quadratic programming problem with fast solution speed:

$$J(\xi(t), u(t-1), \Delta U(t)) = \left[\Delta U(t)^T \varepsilon\right]^T H(t) \left[\Delta U(t)^T \varepsilon\right] + G(t) \left[\Delta U(t)^T \varepsilon\right] + p(t) \tag{24}$$

Each step of model predictive control can also be transformed into a quadratic programming problem with constraints:

$$\begin{aligned} &\min J(\xi(t), u(t-1), \Delta U(t)) \\ &s.t. \begin{cases} \Delta U_{\min} \le \Delta U_t \le \Delta U_{\max} \\ U_{\min} \le A \Delta U_t + U_t \le U_{\max} \\ Y_{h,\min} \le Y_h \le Y_{h,\max} \\ Y_{s,\min} - \varepsilon \le Y_s \le Y_{s,\max} + \varepsilon \end{cases} \end{aligned} \tag{25}$$

In each solution cycle, a series of optimal control output increment sequences in the control time domain can be obtained by calculating the above Quadratic programming problem:

$$\Delta U_t^*(t) = \left(\Delta u_t^*, \ldots, \Delta u_{t+N_c-1}^*\right) \tag{26}$$

According to the principle of model predictive control, only the first element of the control sequence is taken as the actual input increment of the controlled object, then the actual input of the controlled object at the next moment is:

$$u(t) = \Delta u_t^* + u(t-1) \tag{27}$$

After entering the next cycle, repeat the above process to make the unmanned vehicle track the target path.

5 Experimental Verification

The experiment platform of unmanned logistics vehicle was constructed, with the maximum braking acceleration of 3 m/s^2 and the speed coefficient of 0.2 m. The minimum turning radius is 5 m. Carry out data collection along an annular path, and then obtain the change of the established path curvature of the unmanned logistics vehicle. Then, according to the position relationship between the unmanned logistics vehicle and the predetermined path, the proposed method and the reference method [4] Udine are respectively adopted to track the established path, and the starting position of the unmanned logistics vehicle is set as (523350 m, 4057250 m), the initial heading Angle is 0°, the wheelbase of the unmanned logistics vehicle is 1 m, the sampling time is 1 s, the maximum traffic jam is 30 km/h, and the minimum speed is 5 km/h.

The equipment required for real-time tracking of the flow car trajectory without characters is shown in Table 1.

Table 1. Equipment used

Device	Model
GPS	Quectel L80
Vehicle sensor	Gyroscope for STMicroelectronics
Communication devices	Sierra Wireless AirPrime EM7455
Data storage device	SSD hard disk
Tracking system	Google Maps

In order to analyze the performance of the improved Pure Pursuit algorithm, the response speed of the algorithm was used as an indicator to verify the performance of the Pure Pursuit algorithm before and after the improvement.

From the comparison results of response speed shown in Fig. 8, it can be seen that the improved Pure Pursuit algorithm has significantly improved response speed, with a maximum response time of no more than 1.0 s. Therefore, it indicates that the improvements made in this article improve the response speed of the Pure Pursuit algorithm.

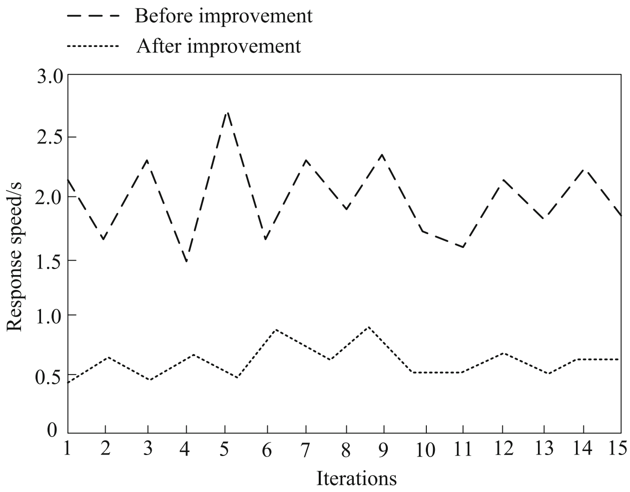


Fig. 8. Response speed of Pure Pursuit algorithm before and after improvement

The path tracking accuracy and lateral tracking error results of the method in this paper and the method in reference [4] are shown in Fig. 9 and 10 respectively.

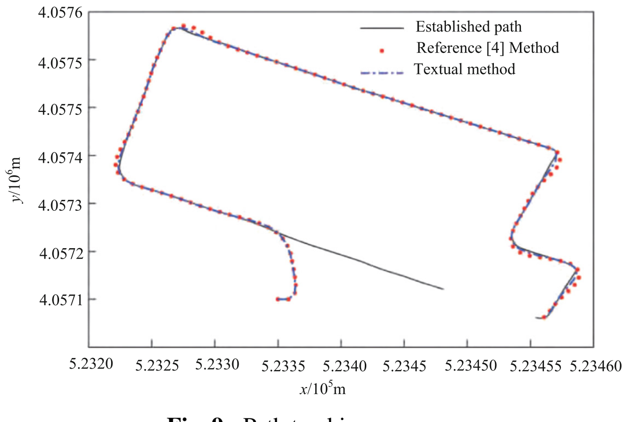


Fig. 9. Path tracking accuracy

From the results shown in Figs. 9 and 10, it can be seen that compared to the method in reference [4], the path tracked by this method is closer to the established path, and the lateral tracking error is smaller. Therefore, it is demonstrated that the method proposed in this paper can improve the real-time path tracking accuracy of unmanned vehicles.

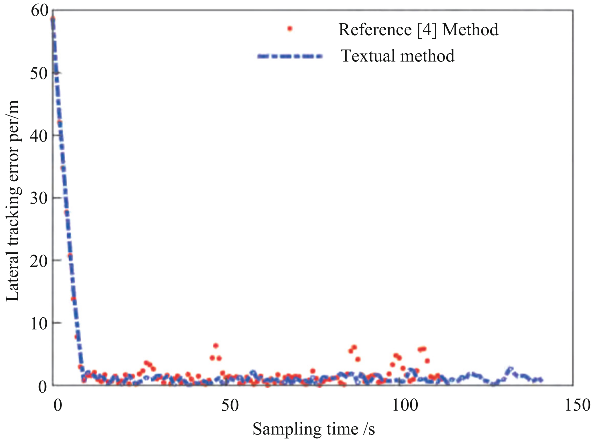


Fig. 10. Lateral tracking deviation

In order to further accurately analyze the tracking performance of the method proposed in this paper, the tracking time of the method proposed in this paper was compared with that of the method proposed in reference [4]. The comparison results of tracking time are shown in Table 2.

Table 2. Tracking time results

Number of experiments	Tracking time consumption/s	
	Proposed method	Reference [4] method
1	1.36	8.96
2	1.05	7.68
3	1.14	9.16
4	1.34	10.56
5	1.21	8.67

From the tracking time results shown in Table 2, it can be seen that under multiple comparative experiments, the tracking time of our method is significantly lower than that of the reference [4] method. The longest detection time of our method is 1.36 s, while the longest tracking time of the reference [4] method is 10.56 s. Therefore, it is demonstrated that the method proposed in this paper can achieve fast tracking of unmanned traffic paths.

6 Conclusion

The electronic tags were adopted to collect the track information of unmanned and vehicle-free vehicles, and the relationship between forward looking distance, speed and curvature was comprehensively considered. The Pure Pursuit algorithm was improved to realize the adaptive change of speed with curvature. The greater the curvature, the lower the vehicle speed, the smaller the forward looking distance, the better the tracking effect. Finally, by solving the objective function, the real-time path tracking of the unmanned logistics vehicle is completed. The proposed method can be used for reference and application in the path tracking of autonomous driving in unmanned logistics.

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References

1. Prokopyev, I.V., Sofronova, E.A.: Study on control methods based on identification of unmanned vehicle model. Procedia Comput. Sci. **186**(15), 21–29 (2021)
2. Heo, J., Ha, J., Lee, J., et al.: Dynamic window approach with path-following for unmanned surface vehicle based on reinforcement learning. Korea Inst. Mil. Sci. Technol. **24**(1), 146–151 (2021)
3. Yoshimoto, Y., Watanabe, T., Nakamura, R., et al.: Effectiveness of digital twin computing on path tracking control of unmanned vehicle by cloud server. IEICE Trans. Commun. **16**(8), 105–109 (2022)
4. Wang, X., Ling, M., Rao, Q., et al.: Research on fusion algorithm of unmanned vehicle path tracking based on improved Stanley algorithm. Automobile Technol. **07**, 25–31 (2022)
5. Li, Z., Wang, Y., Yin, K., et al.: Design of path following controller for unmanned vehicle based on FSMC. J. Hebei Univ. Water Resour. Electr. Eng. **32**(01), 9–15 (2022)
6. Wang, Z., Zhang, H., Zhang, H., et al.: Adaptive event based predictive lateral following control for unmanned ground vehicle system. Int. J. Robust Nonlinear Control **31**(10), 4744–4763 (2021)
7. Mao, X., Yu, B., Shi, Y., et al.: Real-time online trajectory planning and guidance for terminal area energy management of unmanned aerial vehicle. J. Ind. Manag. Optim. **19**(3), 1945–1962 (2023)
8. Li, J., Sun, T., Huang, X., et al.: A memetic path planning algorithm for unmanned air/ground vehicle cooperative detection systems. IEEE Trans. Autom. Sci. Eng. **32**(9), 1–14 (2021)
9. Strawa, N., Ignatyev, D.I., Zolotas, A.C., et al.: On-line learning and updating unmanned tracked vehicle dynamics. Electronics **10**(2), 187–193 (2021)
10. He, Z., Dong, L., Sun, C., et al.: Asynchronous multithreading reinforcement-learning-based path planning and tracking for unmanned underwater vehicle. IEEE Trans. Syst. Man Cybern. Syst. **41**(19), 1–13 (2021)
11. Wang, Z., Xin, P., Sun, H., et al.: Unmanned vehicle path tracking based on contraction constraint model predictive control. Control Decis. **37**(03), 625–634 (2022)
12. Kou, F., Yang, H., Zhang, X., et al.: A lateral control strategy for unmanned vehicle path tracking using state feedback. Mech. Sci. Technol. Aerosp. Eng. **41**(01), 143–150 (2022)
13. Li, Y., Guo, C., Li, Y., et al.: Trajectory tracking control of autonomous vehicle based on steering and braking coordination. Syst. Eng. Electron. **45**(04), 1185–1192 (2023)

14. Qiu, P., Wang, G., Zhao, L., et al.: Unmanned vehicle path planning based on structured road improved artificial potential field method. Mach. Des. Manuf. **03**, 291–296 (2023)
15. Wu, Y., Liang, H.: Research on obstacles avoidance control method of unmanned ground vehicles based on adaptive model prediction. Manuf. Autom. **45**(02), 198–202 (2023)